

Basic Research at the University of Guam Concerning Tropical Cyclone Motion, Structure and Structure Change

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Grant Number N00014-96-1-0744

LONG-TERM GOALS

Our primary long-term goal is to provide comprehensive descriptions of large-scale tropical atmospheric processes that govern the motion, structure and structural evolution of tropical cyclones (TC). It is hoped that our research will transition readily into the knowledge base and applications needed by TC forecasters to better their analyses and forecasts. Another long-term goal is to be able to identify key problem areas in the forecast process that stand the best chance to be alleviated by the results of ONR-sponsored research. This latter goal is fostered by the direct interaction of the University of Guam (UOG) project investigators with the forecasters at the Joint Typhoon Warning Center (JTWC), Guam (soon to be JTWC, Pearl Harbor, Hawaii).

OBJECTIVES

Our research is focused on process studies leading to the development of adequate descriptions and physical explanations for problematic areas in the understanding of TC motion, TC structure and structure change. Working closely with the JTWC (an operational warning center that issues warnings on two-thirds (65 of 100) of the world’s annual output of TCs), we seek to identify the recurring problems that degrade the accuracy of the forecasts of TC motion, intensity and wind distribution. An important spin-off of our project is our ability to define those areas where basic research, vice technology or training, is most appropriate.

APPROACH

Both the PI and Co-PI of this project are synoptic meteorologists with decades of experience in working with meteorological data in the tropics. They are skilled tropical analysts and forecasters with a comprehensive knowledge of tropical climatology and are adept interpreters of multi-spectral (e.g., visible, infrared, and microwave) satellite imagery and NEXRAD products. The Co-PI is a former director of the JTWC. The majority of their research work conducted for ONR consists specifically of the development of conceptual models of the motion, structure and structural evolution of TCs and of

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 1998		2. REPORT TYPE		3. DATES COVERED 00-00-1998 to 00-00-1998	
4. TITLE AND SUBTITLE Basic Research at the University of Guam Concerning Tropical Cyclone Motion, Structure and Structure Change				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Guam,Water and Environmental Research Institute of the Western North Pacific,UOG Station,Mangilao, Guam , ,96911				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM002252.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

the structure and structural evolution of the large-scale environment surrounding TCs (e.g., the TUTT and the monsoon circulation). Further, the interactions of TCs with the large-scale environment are explored. Important findings have been to categorize the monsoon flow (e.g., “monsoon gyre” and “reverse-oriented monsoon trough”) and to document the association of these flow patterns with specific TC structures and motion.

The project investigators have worked closely with JTWC forecasters and technique development personnel to further the understanding of tropical systems (e.g., monsoon depressions, midget TCs, monsoon gyres, and TUTT cells) as revealed by a suite of remote-sensing platforms. The project investigators have tailored their efforts toward the eventual goal of expanding both the “conceptual models” and “model traits” knowledge base of the “Systematic and Integrated Approach to Tropical Cyclone Forecasting” (hereafter, the “Systematic Approach”) (Carr and Elsberry 1994).

WORK COMPLETED

Specific initiatives achieved with recent ONR support includes documentation of the relationships between TCs of the western North Pacific and the character and evolution of the East Asian Monsoon. Synoptic studies have resulted in the development of conceptual models which illustrate the specific TC motions (e.g., north-oriented tracks and binary interactions), and special cases of TC genesis that occur with specific flow patterns of the monsoon circulation over the western North Pacific. These studies have aided studies by other ONR-funded investigators at other institutions.

Our work on the relationships between the large-scale monsoon flow pattern and the associated behavior of tropical cyclones within each specific pattern has been incorporated into the “conceptual models” knowledge base of the “Systematic Approach”. The project investigators have originated terminology to describe the monsoon flow patterns (e.g., the “monsoon gyre” and the “reverse-oriented monsoon trough”) that appear as some of the major environmental patterns that the “Systematic Approach” addresses.

The work of the project investigators on structure and structure change focused on serious deficiencies identified in the historical record of tropical cyclone intensity data bases throughout the Pacific (and in other basins as well). The project investigators have developed a high-confidence TC intensity data base for researchers to use for validating research and technique development. This work was accelerated to accommodate a Naval Research Laboratory initiative that could not begin without portions of this data base. The availability of complementary satellite imagery, synoptic charts, and individual storm folders at the UOG and at the JTWC coupled with the PI and Co-PI's unique knowledge of synoptic data, aircraft data, satellite and radar data, and contacts of the project investigators with personnel at international weather centers (e.g., the JMA and PAGASA) allowed the first part of the project to be accomplished by the UOG team in one-third the time that would have been required at other institutions.

The project investigators have extensively studied the relationship between maximum wind and minimum central sea-level pressure in TCs and have uncovered several deficiencies in operationally used wind-pressure relationships (WPRs). Operational application and the indiscriminate use of the WPRs have deteriorated the accuracy of warning and best-track wind values by smoothing or neglecting natural variations between maximum wind and minimum sea-level pressure. While it may be expedient

to derive the maximum wind in a TC from its measured or estimated minimum sea-level pressure, it is too often used to support a lower wind estimate than that which was actually measured.

The project investigators have completed preliminary work on TC structure and intensity as revealed by new remote-sensing technologies. With the loss of dedicated aircraft reconnaissance support in 1987, the JTWC (and nearly all other TC warning agencies except the U.S. National Hurricane Center) now must rely upon sparse synoptic data and data gathered by meteorological satellites (METSAT) to diagnose TC intensity and wind distribution. Techniques for estimating TC intensity, though relatively accurate (e.g., Dvorak's techniques), are dated and there are some areas for improvement. Additionally, new active and passive sensors have come on line (e.g., the water vapor imagery at 6.7 microns, other IR channels, microwave imagery, Doppler radar, and scatterometers). Exploration of new remote sensing technology for TC applications is currently an exciting and fruitful area of research.

Additional work completed, or for which preliminary results have been obtained, includes:

- (1) further analysis of the global distribution of tropical cyclones;
- (2) further analysis of the properties of TC outer wind distribution;
- (3) the development of a scale relating TC damage to TC intensity for use in the tropics of the western North Pacific;
- (4) the assessment of techniques for using microwave imagery to diagnose TC intensity (stand alone or in concert with other spectral windows); and,
- (5) an examination of water-vapor winds to explore the properties of TC outflow, and the relationship between the extent of cyclonic flow at high altitude and the intensity of the TC.

RESULTS

An examination of the observed minimum central sea-level pressure and the accompanying value of the observed maximum sustained surface wind in very small TCs shows substantial differences from those given by operationally used wind-pressure relationships (WPRs) for TCs. The very small TC tends to have a higher minimum central pressure for a given maximum sustained wind speed than expected. Very small TCs were found to have wind profiles that differed from those of larger TCs in the rate at which the wind decreases beyond the radius of maximum wind. Using the gradient wind equation to compute the pressure differential between the center of a TC and its environment, one finds that differences in the rate of diminution of the wind beyond the radius of maximum wind can account for the observed discrepancies of the WPRs in very small TCs from those of larger TCs and the operational ones. A separate WPR for the very small TC emerges from both observation and theory indicating that for a given maximum wind speed, the central sea-level pressure tends to be approximately 15-20 hPa greater than expected from the operational TC WPRs.

In a new twist to the problem, the measured wind and minimum sea-level pressures recorded during the passage of Typhoon Paka over Guam the night of 16 December 1997 indicates that TC WPRs are even more problematical. Paka (a large TC with a radar-observed eye diameter of nearly 40 nm when it passed over Guam) had a sea-level pressure that was nearly 25 mb too high for its measured maximum wind speed using the standard WPR for the western North Pacific. The observed natural variability in the relationships between maximum wind and minimum pressure is larger than what may have been previously thought, and may render the traditional practice of smoothing best-track intensities by central pressure readings dubious -- even those minimum pressures derived by aircraft.

Problems with existing techniques for diagnosing the intensity of TCs from satellite imagery have been noted (e.g., a tendency for Dvorak analysis to yield intensities that are too low for TCs that are undergoing extratropical transition). An effort to improve the diagnosis of TC structure and intensity through the use of microwave imagery is ongoing. The UOG project investigators have worked closely with JTWC forecasters to develop a knowledge base for interpreting METSAT data. For example, we have uncovered a suite of structural characteristics of TCs as revealed by microwave imagery that are related to the intensity. It has been demonstrated that microwave imagery can be used to diagnose TC intensity, albeit with an accuracy not yet as good (on average) as conventional Dvorak analysis. We conclude that the microwave imagery is best used in conjunction with other spectral windows to improve TC intensity diagnosis from METSAT imagery.

Whereas much work has gone into studying the basic principles of TC motion, little is known about the mechanisms of TC intensification. Using METSAT data and objective techniques applied to the METSAT data (e.g., the digital Dvorak algorithm), the project investigators have established an empirical knowledge base of the characteristics of TC intensification. Similar to the role played by the project investigators in establishing the motion characteristics of TCs undergoing interactions with monsoon gyres, reverse-oriented monsoon troughs, and some of the general characteristics of the binary interaction of TCs, the project investigators have established conceptual models for TC structure and structural evolution (which includes genesis, development, intensification, weakening, and specific structural changes such as extratropical transition). Some common features emerge from the digital Dvorak (DD) time series of very intense TCs: (1) the DD numbers often exhibit much larger fluctuations than indicated on the best track, (2) the DD numbers tend to rise faster than the best track intensity during the intensification phase, (3) the DD numbers peak earlier in almost all cases when compared with the best track intensity, and (4) there is a general tendency for a diurnal cycle. Concentric eye wall cloud formation is almost universal with the most intense TCs (which is a problem for conventional Dvorak analysis), and microwave imagery is very useful for depicting this process.

IMPACT/APPLICATIONS

The most significant potential future impact of our research on the scientific study of TCs is a demonstration that the best-track intensity data bases are potentially flawed. The practice of using pressure to constrain the maximum wind is wrong, and the very wind-pressure relationships used to do this are not reliable. Our work on the effects of the monsoon circulation on TC motion and structure may have relevance to scientific studies aimed to predict the possible changes to TC distribution from climate change. In the western North Pacific, the location and character of the monsoon trough governs the distribution of TCs, and any climate change scenario must address how the monsoon trough is to be affected, and not simply address the thermodynamics of individual TCs over warmer water.

Our work is readily adaptable for inclusion in the “conceptual models” knowledge base of the “Systematic Approach”. The “monsoon gyre” and the “reverse-oriented monsoon trough” already are included.

TRANSITIONS

(1) New methods for evaluating the intensity of TCs undergoing extratropical transition have been developed and implemented at the JTWC.

(2) Our descriptions of the monsoon flow patterns and the specific TC motion and structure associated with these flow patterns is already included in the “Systematic Approach”.

(3) Uses of microwave imagery for locating and estimating the intensity of TCs have been developed and implemented by the JTWC.

(4) The project investigators advise the JTWC and the COMNAVMAR admiral concerning the status of ENSO, the possible effects of ENSO on the distribution of TCs in the western North Pacific basin, and the possible effects of ENSO on the water supply of Guam, the CNMI, and the Federated States of Micronesia.

(5) The project investigators provide, on an ongoing basis, expert technical support to the post-analysis effort of the JTWC as it appears in their Annual Tropical Cyclone Report.

(6) We have established links with international agencies to acquire data on TC landfall events.

(7) We have provided technical support to JTWC personnel to devise new applied techniques, and to jointly author research papers detailing these efforts and other research initiatives (e.g., a study of the use of microwave imagery to diagnose TC intensity).

RELATED PROJECTS

The UOG project investigators are involved in other projects that may yield some beneficial results to our efforts for ONR. The UOG is a designated ENSO applications center. The project investigators have been making prediction of the rainfall and TC distribution for the western Pacific basin based upon ENSO. The changes in TC distribution attributable to ENSO have direct transitions to the JTWC and have had spin-offs for our ONR research effort (e.g., ENSO effects the TC distribution and the monsoon circulation of the western North Pacific).

The UOG project investigators have a contract with NASA. A satellite ground station has been erected at our office site at the UOG. Our image processing equipment allows us similar capabilities of capture and manipulation of GMS satellite imagery as is achieved by the MIDDAS satellite image processing equipment at the JTWC.

The UOG project investigators have also been selected to participate as a TRMM validation site. For this effort we have erected a range gage network the southern Mariana Islands, and may acquire equipment to store NEXRAD products. NEXRAD products are extremely valuable in the study of TCs that pass near Guam (approximately five per year pass within the range of Guam’s NEXRAD).

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PUBLICATIONS

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(Authored and/or contributed to seven abstracts for the upcoming 23rd Conference on Hurricanes and Tropical Meteorology in Dallas, TX, January 1999.)

IN-HOUSE/OUT-OF-HOUSE RATIOS

No work specified by this contract was done under the direct support of a federal government organization, although the project investigators often worked closely with personnel at the JTWC. All of the work was done through an Academic Institution, namely, the University of Guam.